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Effects of elevated UV-B radiation and N deposition on the decomposition of coarse woody debris

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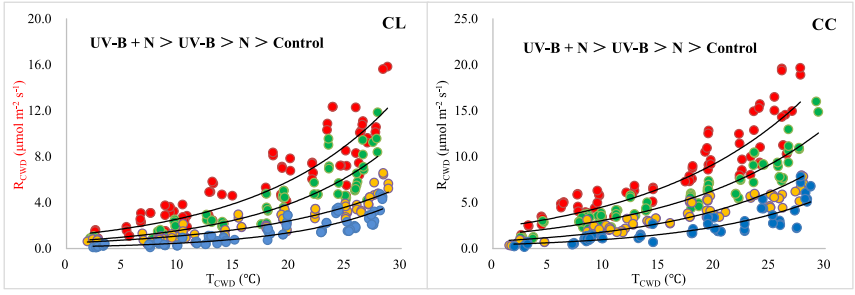
HIGHLIGHTS

- Both UV-B and N treatment significantly accelerated the R_{CWD}.
- The combined treatment effect exceeded the sum of the individual treatment effects.
- UV-B, N, UV-B + N treatment effects were further amplified by increasing temperature.
- Ozone depletion, N, warming may work synergistically to accelerate CWD decomposition.

GRAPHICAL ABSTRACT



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ABSTRACT

Increases in nitrogen (N) deposition and ultraviolet-B (UV-B) radiation play an important role in global climate change. Because coarse woody debris (CWD) represents a sizeable proportion of total carbon (C) pool in forest ecosystems, understanding the response of CWD decomposition to increased UV-B and N deposition become necessary for evaluating forest C storage under global climate change. In this study, we investigated the respiration of CWD (R_{CWD}) in response to increased UV-B and N deposition over a two-year period for two tree species in subtropical Chinese forests: *Cunninghamia lanceolata* (Lamb.) Hook. (CL) and *Cinnamomum camphora* (L.) Presl (CC). We found that N and UV-B treatment, alone or in combination, significantly promoted R_{CWD}, which was further magnified by increased temperature. Moreover, the combined treatment (UV-B + N) far exceeded the sum of the individual effects of N and UV-B treatments. Our results indicated that the three components of global climate change (increased UV-B, N deposition, and warming) worked interactively to accelerate CWD decomposition in forest ecosystems, suggesting that the biogeochemical cycling of subtropical forests could be altered greatly in the future, and this alteration must be considered in modelling the effects of global climate change.
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1. Introduction

Coarse woody debris (CWD) contains a large stock of carbon (C) and nutrients, and its decomposition plays an important role in C and nutrient cycling in forest ecosystems (Harmon et al., 1986; Hicks et al., 2003).

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It was estimated that CWD accounted for about 5%, 18%, and 10% of the total ecosystem C pool, respectively, in boreal, temperate, and tropical forests (Pregitzer and Euskirchen, 2004). The longevity or turnover time of C stored in CWD depends on its decomposition rate, which in turn determines the amount of CO_2 released (net emission) from CWD because the respiration C loss represents the major pathway of CWD decomposition (Mackensen and Bauhaus, 2003). For example, Chambers et al. (2001) found that about 76% of all C in dead logs was lost through respiration. Therefore, the respiration C loss of CWD (R_{CWD}) contributes significantly to forest ecosystem C flux.

Along with global warming, N deposition and elevated ultraviolet-B radiation (UV-B, wavelength 280–320 nm) are both critical drivers of global climate change. Over the last 30 years, because of ozone depletion, UV-B radiation reaching the Earth's surface has increased by approximately 5% in northern mid-latitudes, and that increase will continue until the mid-21st century (Herman, 2010). Since the industrial revolution, reactive N productions increased from 15 Tg N yr^{-1} in 1860 to 187 Tg N yr^{-1} in 2005, and is predicted to increase by 50% to 100% by 2030 (Galloway et al., 2008; Reay et al., 2008). Subtropical China is predicted to become the worst N deposition region in the world by 2030 (Mo et al., 2006; Reay et al., 2008). Therefore, it is necessary to study the effects of elevated UV-B, N deposition, and their interaction on CWD decomposition (and thus respiration) in subtropical forest ecosystems.

N deposition and elevated UV-B radiation could potentially affect various terrestrial ecosystem processes, including C loss of respiration in forest ecosystems. Previous studies reported that elevated UV-B radiation could increase (Austin and Vivanco, 2006; Lin and King, 2014; Baker and Allison, 2015; Day et al., 2018), decrease (Pancotto et al., 2003; Lambie et al., 2014), or have no effect (Uselman et al., 2011; Song et al., 2013) on litter decomposition. Similarly, nitrogen deposition also showed positive (Bebber et al., 2011; Crowther et al., 2015; Zhang et al., 2016), negative (Qiao et al., 2016), or no effects (Maestrini et al., 2014; Chen et al., 2016) on CWD decomposition. Furthermore, the interaction of N deposition and elevated UV-B on litter decomposition was also studied (Song et al., 2014a,b). However, no studies have examined CWD decomposition in response to elevated UV-B, alone or together with N deposition.

Similar to litter decomposition (Bradford et al., 2017), the activity of microorganisms was reported to determine the respiration of CWD (R_{CWD}) (Chambers et al., 2001), especially, the specific composition of fungi and bacteria (Maynard et al., 2017; Tláskal et al., 2017; Mäkipää et al., 2018). Fungal colonization is considered a dominant driver of dead wood decomposition (Bradford et al., 2014; Van der Wal et al., 2014; Fukasawa, 2018), and lignocellulolytic fungi are critical determinants of carbon sequestration rates and nutrient cycling in forest ecosystems (Hu et al., 2017). Therefore, the dominant decomposing agents of wood are fungi because of their ability to breakdown lignin and cellulose (Boddy, 2000). Consequently, the response of fungi to environmental changes could determine the rate of CWD decomposition under global climate change, including N deposition and elevated UV-B radiation. In addition to decomposer communities, environmental factors, such as substrate moisture content and temperature, also influence CWD decomposition (Rubenstein et al., 2017) because decomposer communities were highly sensitive to these two factors (e.g., moisture content and temperature) (Hu et al., 2017). However, how elevated UV-B, N deposition, and their interaction affect R_{CWD} and how these effects change with environmental factors are still unclear.

Previous studies have found that litter decomposition was significantly affected by elevated UV-B (Agrawal and Kumari, 2013), increased N deposition (Zheng et al., 2017), and their interactions (Song et al., 2014a,b). However, CWD differs from litter in both morphology and chemical composition. Therefore, CWD decomposition may respond to elevated UV-B, increased N deposition, and other environmental variables (e.g., temperature and moisture) differently from litter decomposition. We designed a two-year experiment to address the following research questions: 1) Do N deposition and elevated UV-B radiation accelerate CWD decomposition? 2) Are the combined effects of N deposition and elevated UV-B on CWD decomposition significantly higher than the sum of their individual effects? And 3) Do the effects of N deposition and elevated UV-B on CWD decomposition change with CWD temperature and moisture content? Coarse woody debris of two tree species, *Cunninghamia lanceolata* (Lamb.) Hook. (CL) and *Cinnamomum camphora* (L.) Presl (CC), were used in the experiment. Both species are widely distributed and planted in subtropical China (Yang et al., 2004; Song et al., 2012).

2. Materials and methods

2.1. Study area

This field study was conducted in Jiangxi Agricultural University (115°83′ E, 28°76′ N), Nanchang City, Jiangxi Province of subtropical China. The study area is characterized as a subtropical monsoon climate with four distinct seasons. The mean annual temperature and precipitation ranges from 17.0 to 17.7 °C and from 1600 to 1700 mm. The site has an average of 147–157 rainfall days per year. The air temperature and monthly rainfall during the study period are given in Fig. 1.

2.2. Experimental treatments

A complete randomized design, consisting of four treatments and three replicates per treatment, was applied to the study. The four different treatments were increased UV-B radiation (UV-B), increased N deposition (N), increased UV-B radiation and N deposition (UV-B + N), and control treatment (CK). A total of 12 plots, three replicates per treatment, were set up in this study. The size of each plot was 1.3 m × 2.3 m, and plots were 10 m apart from each other to ensure sufficient buffer. Topsoils (0–10 cm) were collected from the coniferous and broadleaved mixed forest where the CWDs were collected. These soils were sieved (4 mm) and filled uniformly into each plot to reach a depth of 10 cm (Song et al., 2014a). Soil organic matter, total N, hydrolyzed N, phosphorus (P), available P, and available potassium (K) content were 53.37 g kg^{-1}, 2.13 g kg^{-1}, 221.36 mg kg^{-1}, 0.33 g kg^{-1}, 4.27 mg kg^{-1}, and 49.65 mg kg^{-1}, respectively. Soil pH and bulk density were 4.7 and 1.43 g cm^{-3}. To avoid any potential confounding effect from vegetation growth, each experimental plot was initially set up on bare ground consisting of the above soils under a forest canopy, and manually removed the growth of subsequent vegetation during the study period.

Artificial irradiance was used to regulate elevated UV-B via fluorescent UV-B lamps (UV-B313EL, Beijing Lighting Research Institute, Beijing, China), and installed 1 m above the ground (Song et al., 2012). Cellulose triacetate film was wrapped around each lamp, which effectively isolated all UV-C but not UV-B (280–320 nm) or UV-A

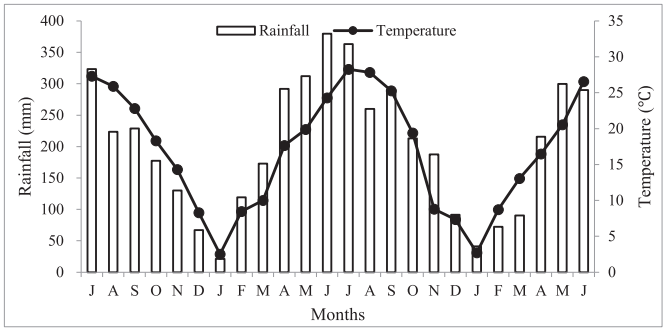
Rainfall
Temperature
Rainfall (mm)
Temperature (°C)
Months
J A S O N D J F M A M J J A S O N D J F M A M J
0 50 100 150 200 250 300 350 400
0 5 10 15 20 25 30 35

Fig. 1. Average monthly rainfall and air temperature from July 2015 to June 2017 in the study region. Note: J, A, S…was the abbreviation for each month (from July 2015 to June 2017, twenty-four months in total).

(315–400 nm). Similar to many previous UV-B studies, UV-A was not controlled in this study (Hoorens et al., 2004; Smith et al., 2010). During the two-year experimental period, UV-B lamps operated from 9:00 a.m. to 4:00 p.m. under cloudless weather condition. In addition, lamp height from the ground was adjusted monthly to ensure a 10% increase above ambient levels of UV-B (Song et al., 2012). The UV-B radiation intensity of each treatment of this study is given in Table 1. Radiation was determined using a UV-297 radiometer (Photoelectric Instrument Factory of Beijing Normal University, China).

The N treatment was applied 60 kg N ha^{-1} yr^{-1} ammonium nitrate (NH_4NO_3). To achieve this targeted amount, 7.5 g of NH_4NO_3 and 150 mL of purified water were mixed. At the beginning of every month, a sprayer was using to spray the mixed solution onto each plot throughout the experimental period (Mo et al., 2006; Fang et al., 2007).

The same with above, 10% UV-B increase and 60 kg N ha^{-1} yr^{-1} N deposition were implemented for the UV-B + N treatment. To ensure the same level of shading effect from the installation of lamp arrays for the UV-B and UV-B + N treatments, dummy lamps were also installed for both control and N treatment plots. Similarly, control and UV-B treatment plots were also irrigated with 150 mL of N-free water.

The experimental materials were selected from the downed CWD pieces of the two study species: CL and CC. All CWD pieces were fresh wood samples (the bark was complete, and the sapwood was intact) (Harmon et al., 1986), which measured 150 cm long and 16 cm in the central diameter (Table 2). As expected, the CWD from the two species significantly differed in several measured properties, including wood density and the content of carbon, nitrogen, lignin and cellulose. Within each experimental plot, two replicate CWD segments for each species were placed side by side (20 cm from each other), flush with the ground, and 35 cm from the plot boundary. As a result, each tree species had 24 segments in the experiment (2 repeated segments × 3 sample plots × 4 treatments).

2.3. Measurements of R_{CWD}

We used neutral sealant to affix the respiration collars (PVC rings, 2 mm thick × 10 cm diameter × 5 cm height) to the surface of each CWDs in June 2015. The R_{CWD} was determined using a soil CO_2 flux chamber within the LI-COR portable photosynthesis system (LI-6400-09, LI-COR, Inc., Lincoln, Nebraska). (Herrmann and Bauhus, 2008; Wu et al., 2018). The collars were installed at about 50 cm from one end and about 100 cm from the other end of each CWD. The longer end was used to destructively sample for the moisture content measurement.

From July 2015 to June 2017, at the beginning of every month, we measured the CWD respiration of each CWD section in a random order between 09:00 and 11:00 a.m. The measurements of all CWD sections were completed within 1 or 2 rainless days, before N addition. The used PVC rings were checked every month and resealed if needed.

2.4. T_{CWD} and M_{CWD} measurement

Temperature (T_{CWD}) and Moisture content (M_{CWD}) of CWD were measured along with the measurement of CO_2 flux. A hand-held long-stem thermometer (Model SK-250WP, Sato Keiryoki Mfg. Co. Ltd., Tokyo, Japan) was used to determine T_{CWD} at approximately 2 cm depth of each CWD. During each R_{CWD} measurement, one 2 cm thick disk of each CWD was cut to determine the wet weight and sealed into a plastic bag before being transferred to the laboratory to preserve moisture content (Guo et al., 2014). All CWD disk samples were collected >80 cm away from the collar installed on each CWD segment. After each field measurement, these samples were oven dried at 70 °C to determine the M_{CWD}. M_{CWD} in this study was calculated by weight using Eq. (1).

$$M_{CWD} = \frac{W_{wt} - W_d}{W_d} \quad (1)$$

where M_{CWD} (%) was the moisture content of each CWD during each measurement, W_{wt} (g) was the wet wood weight, and W_d (g) was the dry weight.

Table 1
UV-B radiation intensity (mW·cm^{-2}) in each treatment (n = 3) of this study and Wu et al. (2018).

Resoures	Treatments (n = 3)	Designed value	Actual value
Our study	UV-B + N	0.276	0.276
	UV-B	0.276	0.277
	N	0.251	0.253
	Control	0.251	0.251
Wu et al. (2018)	Control	0.251	0.252
	Shaded 30%	0.176	0.176
	Shaded 60%	0.100	0.101
	Shaded 100%	0.000	0.001

2.5. Nutrient measurement

The C concentrations of each measured CWD sample were determined using a TOC analyzer (Vario TOC, Elementar, German). The lignin and cellulose concentrations of CWD samples were determined using the ADF-sulphuric method (Rowland and Roberts, 1994). The N concentrations of each measured CWD sample were determined using the Kjeldahl method (K-370, Buchi Scientific Instruments, Switzerland).

2.6. Data analysis

Two-way repeated-measures ANOVA was used to test the effects of species, treatment, and their interaction on the respiration, temperature, and moisture content of CWD. Duncan post-hoc tests were used to examine differences between species and among treatments. The mean value of each variable for each treatment and tree species was calculated from the 24 monthly measurements. All data analyses were performed using SPSS 19.0 (SPSS Inc., Chicago, USA). Results were reported as significant at $p < 0.05$.

An exponential function was used to determine the relationship between respiration and temperature of CWD (Eq. (2)):

$$R_{CWD} = ae^{bT_{CWD}} \quad (2)$$

where a and b are regression coefficients and T_{CWD} is the temperature of different CWDs.

3. Results

3.1. Temporal trends in R_{CWD}

For each species, R_{CWD} was significantly affected by treatment and measurement month, but not by their interactions ($p < 0.05$) (Fig. 2). Regardless of treatment, R_{CWD} displayed a similar monthly fluctuation dynamic, with the lowest and highest values observed in January 2015 and 2016, and in July 2015 and 2016, respectively (Fig. 2). For each species, R_{CWD} significantly ($p < 0.05$) differed from each other among the four treatments. R_{CWD} was highest in UV-B + N treatment and lowest in control during the study period. Both N and UV-B treatments had higher R_{CWD} than the control, with the UV-B treatment being significantly higher than N treatment ($p < 0.05$).

3.2. Average trends in R_{CWD}

Between the two species, CC always showed a significantly ($p < 0.05$) higher R_{CWD} than CL (Table 3). However, the relative difference between the two species was not consistent among the four treatments, with the two treatments under N addition (UV-B + N and N) showing a

Table 2
The initial morphology and chemistry (mean ± SE) of the coarse wood debris (CWD) for the two studied tree species (n = 24). CL = *Cunninghamia lanceolata*; CC = *Cinnamomum camphora*. Different lowercase letters in the same column indicate significant differences ($p < 0.05$) between species. Note: Duncan's post-hoc tests were used to examine differences between species and among treatments.

Tree species (n = 24)	Average diameter (cm)	Average length (cm)	Average CWD density (g cm^{-3})	C (g kg^{-1})	N (g kg^{-1})	Lignin (%)	Cellulose (%)	Decay state
CL	15.54 ± 2.67^{a}	146.35 ± 3.86^{a}	0.411 ± 0.06^{a}	387.71 ± 9.82^{a}	4.39 ± 0.44^{a}	18.35 ± 1.86^{a}	41.84 ± 2.38^{a}	Fresh wood
CC	15.41 ± 1.99^{a}	145.76 ± 3.29^{a}	0.464 ± 0.08^{b}	415.17 ± 9.33^{b}	4.71 ± 0.69^{a}	23.16 ± 1.91^{b}	35.14 ± 2.69^{b}	Fresh wood

smaller difference. N and UV-B treatments significantly enhanced R_{CWD} of the two tree species when compared with the control, which increased by 67%, 149%, and 273% for CL and 58%, 152%, and 259% for CC, respectively, for N, UV-B and UV-B + N treatments (Table 3). The interaction between UV-B and N further enhanced the R_{CWD}, and the result of 273% and 259% increase due to UV-B + N was larger than the 216% and 211% increase that resulted from adding the individual UV-B and N for CL and CC, respectively (Table 2).

3.3. Relationships between T_{CWD} and R_{CWD}

For each species and treatment combination, there existed a significantly positive relationship between R_{CWD} and T_{CWD}. Among the eight species and treatment combinations, T_{CWD} explained 80.4–87.7% of the total variation of R_{CWD} (Fig. 3). At any given T_{CWD}, the treatment (UV-B, N, or UV-B + N) significantly increased R_{CWD} when compared with control, with UV-B + N > UV-B > N. For each species, the absolute difference of exponential functions increased with increasing temperature among the four UV-B and N treatments (Fig. 3).

4. Discussion

4.1. UV-B effects

Although our study is the first to investigate how elevated UV-B radiation affected CWD decomposition, many other studies have examined the influence of UV-B on leaf litter decomposition in different ecosystems. Some of these studies reported a significantly positive effect of elevated UV-B on litter decomposition. Over the last 30 years, UV-B radiation on the Earth's surface has increased by about 5% in northern mid-latitudes due to ozone depletion (Herman, 2010). Based on the annual ozone depletion rate of 0.27% reported in subtropical China (Liao et al., 2007), UV-B radiation is estimated to increase by approximately 10% by 2045 in our study region. Our results indicated that the expected increase in UV-B radiation would significantly accelerate CWD decomposition in subtropical Chinese forests.

Although we did not study the mechanism of how UV-B change accelerated CWD decomposition, previous studies on litter decomposition have reported that elevated UV-B increased relative enzyme activity (Jones et al., 2016; Austin et al., 2016), microbial community activity (Gallo et al., 2006; Berg and McClaugherty, 2008; Lin et al., 2018), and breakdown of wood chemical structure (Day et al., 2007; Austin et al., 2016). Therefore, the accelerated CWD decomposition observed in our study is also likely caused by enhanced activities from decomposing communities under conditions of increased UV-B.

4.2. Nitrogen deposition effects

We found that N treatment accelerated the decomposition of CWD by about 60% (Table 3 and Fig. 2). This magnitude of increase, although less than that caused by UV-B treatment, is much higher than those reported in other CWD decomposition studies. For example, Bebber et al. (2011) indicated that N addition (2.8 kg N ha^{-1} year^{-1}) significantly increased *Fagus sylvatica* wood mass loss by 8.9%. For litter decomposition, previous studies found that N addition at 5 g N m^{-2} year^{-1} enhanced the mass loss of *Solidago canadensis* litter by 6–10% (Schuster, 2016), while N addition at 10 g N m^{-2} year^{-1} increased the mass loss by 16–24% (Gong et al., 2015; Liu et al., 2015). In this study, we used N addition at 60 kg N ha^{-1} year^{-1}, which was based on the maximum value of 63.53 kg N ha^{-1} year^{-1} by 2030 predicted for subtropical China (Lü and Tian, 2007). Our results indicated that CWD decomposition in subtropical forests could increase by 60% under the predicted level of N deposition in the near future.

Nitrogen deposition can promote CWD decomposition by improving N immobilization (Kaakinen et al., 2007), N availability (Hobbie, 2005; Qiao et al., 2016; Zhang et al., 2016), and microbial activity (Hobbie, 2005; Bebber et al., 2011; Crowther et al., 2015). For example, enhanced N deposition could alter CWD chemistry by changing nutrient stoichiometry and concentrations because of increased N immobilization during the CWD decomposition process (Kaakinen et al., 2007), which could further impact microbial composition and activity (Bebber et al., 2011; Crowther et al., 2015). In addition, it is well known that nitrogen deposition promoted initial decay rate of plant litters, but it reduces decay rate of lignin and increases final remaining mass after the decay period. Because we only measured the instantaneous respiration rate

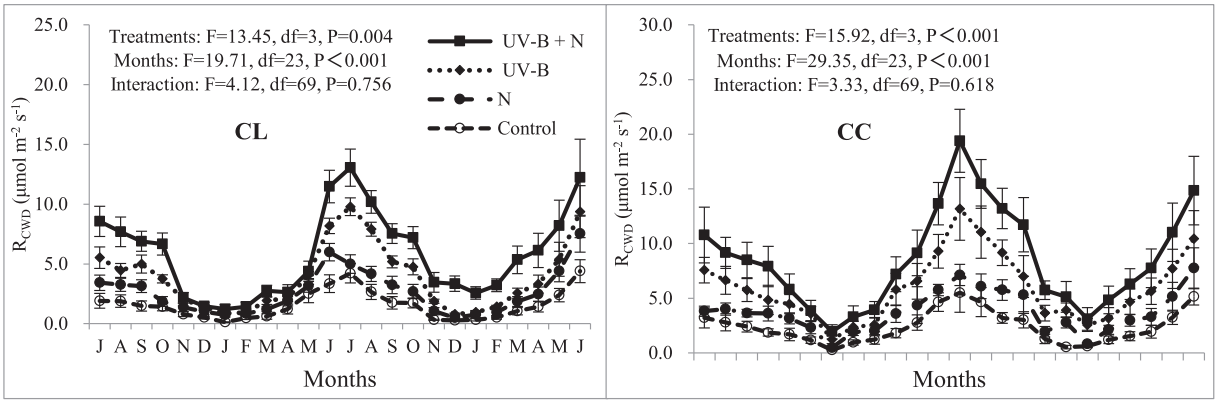

Fig. 2. Monthly dynamics of R_{CWD} (μmol m^{-2} s^{-1}) for the four treatments by species. R_{CWD} = respiration rate of CWD; CL = *Cunninghamia lanceolata*; CC = *Cinnamomum camphora*. Note: J, A, S…was the abbreviation for each month (from July 2015 to June 2017, twenty-four months in total). The error bars of this figure are standard errors.

Table 3
Average R_{CWD} (±SE) by species and treatment (n = 3). R_{CWD} = respiration rate of CWD; CL = *Cunninghamia lanceolata*; CC = *Cinnamomum camphora*. Different uppercase letters indicate significant differences among treatments (UV-B + N, UV-B, N, and *Control*) of the same species (CL or CC) at $p < 0.05$. Different lowercase letters indicate significant differences between two species for the same treatments ($p < 0.05$). Note: Duncan's post-hoc tests were used to examine differences between species and among treatments.

Tree species	Treatments	R_{CWD} (μmol m^{-2} s^{-1})
CL	UV-B + N	5.82 ± 0.99^{Aa}
	UV-B	3.89 ± 0.55^{Ba}
	N	2.60 ± 0.51^{Ca}
	Control	1.56 ± 0.40^{Da}
CC	UV-B + N	8.48 ± 1.70^{Ab}
	UV-B	5.95 ± 1.28^{Bb}
	N	3.74 ± 0.74^{Cb}
	Control	2.36 ± 0.58^{Db}

in relatively early stage (fresh wood) of CWD decomposition, we must acknowledge this limitation of our study.

4.3. Interactive effects of UV-B and N deposition

A previous study found that the combined N deposition and UV-B treatment (a 30 kg N ha^{-1} yr^{-1} N addition and a 10% UV-B increase) increased litter decomposition of Moso bamboo by about 55%, and this combined effect was more than the individual effect due to UV-B or N treatment, but less than the sum of the two individual effects (Song et al., 2014a). Our study used the same level of UV-B but a higher level of N treatment compared to Song et al. (2014a). As a result, the combined N and UV-B treatment increased R_{CWD} by >250% (Table 3 and Fig. 2). These increases far exceeded the sum of the individual effects of N and UV-B (about 210%) observed in our study, suggesting that the combined N and UV-B treatment produced a synergetic effect on CWD decomposition. Furthermore, we also found that this synergetic effect increased with increasing temperature (Fig. 3). Given that elevated UV-B, N deposition, and global warming are ongoing in concert, their synergetic effects on CWD decomposition will be further magnified, which could have significant implications on C and nutrient cycles in forest ecosystems.

Our study found that elevated UV-B treatment affected CWD decomposition much more than N deposition treatment (~150% versus <67% increase), suggesting that the breakdown of CWDs by UV-B photodegradation was more significant than N limitation for CWD decomposition. In addition, a previous study reported that photodegradation (including UV-B) accelerated ecosystem N cycling, which may also promote CWD decomposition (Asao et al., 2018).

Unlike litter decomposition, CWD decomposition may be subjected to a "priority effect" because some endophytic fungi, due to their presence before tree death and fallen down, have a competitive advantage for available resources over other later-arriving microorganisms (Hiscox et al., 2015; Song et al., 2017). Specifically, during early decomposition, this priority effect could promote a fungal dominance of wood compound turnover with easily available C (Boddy, 2001; Rajala et al., 2012), and some enzymes produced by these fungi are critically important to the degradation of wood polymer structures in the early decay stages (Stokland et al., 2012). Although litter also contains endophytes to promote its decomposition rates (Siegrist and McCulley, 2007), CWD hosts a much higher abundance and diversity of microorganisms than other types of leaf litter (Grove, 2002; Stokland et al., 2012). Given our CWD samples were all at an early decay stage (fresh wood), the priority effect becomes even more prominent and may have magnified the treatment effects observed.

Although a significant influence of UV-B and N treatments on CWD decomposition was found in this study, further studies are still needed to elucidate the influence of N deposition and UV-B radiation on CWD decomposition. First, N and UV-B are only two of the many environmental factors affecting the decomposition of CWD, and their effects could vary with forest type, tree species, and decay stage. Second, the surprisingly high increase in R_{CWD} from the combined effect of N deposition and elevated UV-B, which was 2.5 times more than the control, likely represents the upper limit of the increase. CWD materials in forest ecosystems are often under heavy or partial shade from forest canopy and other understory vegetation, which would greatly reduce the amount of UV-B radiation received by CWD on the soil surface (Brown et al., 1994) even under the predicted scenario of 10% increase in 2045. Indeed, our previous study found that 60% shading reduces R_{CWD} by >30% (Wu et al., 2018). Finally, the respiration rate of CWD used in this study is an instantaneous measure of decomposition, which does not directly reflect the mass remaining after the whole decay process.

5. Conclusions

Elevated UV-B radiation and enhanced N deposition are two important drivers of global environmental change that could significantly affect CWD decomposition. Exposure to the elevated UV-B or enhanced N deposition resulted in a significant acceleration of the CWD decomposition for *Cunninghamia lanceolata* and *Cinnamomum camphora*. The combined treatment (UV-B + N) resulted in an effect higher than the sum of individual effects due to UV-B and N treatments. Moreover, these treatment effects were further amplified with increasing temperature. Our results indicated that elevated UV-B radiation, enhanced N

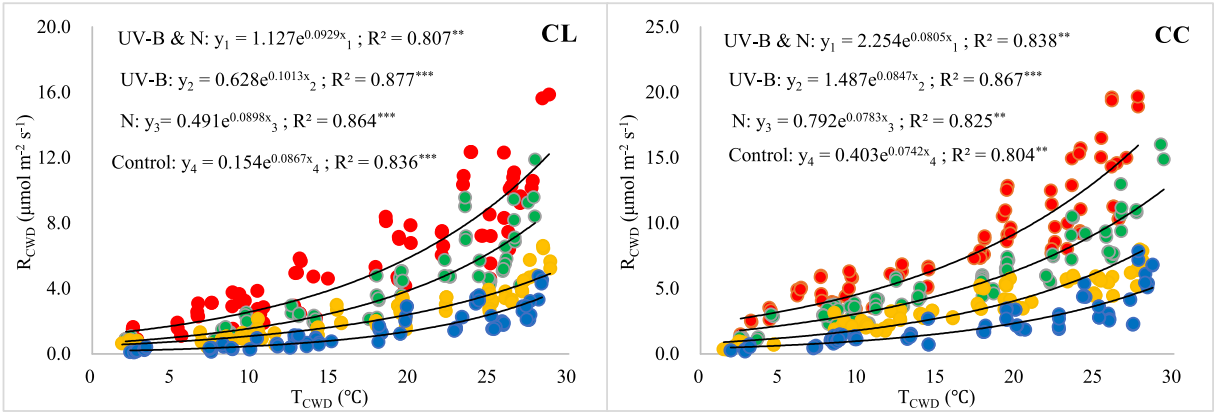

Fig. 3. R_{CWD} in relation to T_{CWD} by species and treatment. The relationship between R_{CWD} and T_{CWD} was expressed in Eq. (2) based on Lloyd and Taylor (1994): $R_{CWD} = ae^{bT_{CWD}}$, Where a and b are regression coefficients obtained using a nonlinear least square regression. Red color represents UV-B + N treatment, green color represents UV-B treatment, orange color represents N treatment, and blue color represents control treatment. ^{ns}not significant, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. R_{CWD} = respiration rate of CWD; T_{CWD} = temperature of CWD; CWD = Coarse woody debris; CL = *Cunninghamia lanceolata*; CC = *Cinnamomum camphora*.

deposition and global warming could have a profound effect on CWD decomposition in subtropical forest ecosystems. Findings from our study will contribute to better understanding the interactive effect of enhanced UV-B and N deposition on biogeochemical cycling and primary productivity in terrestrial ecosystems under global warming.

Contributions

The authors contributed equally to investigate, collect data and complete the project. C.S.W., H.K.W., Q.F.M., Z.J.Z., G.X.H., F.Q.K., Y.Q.L, and G.G.W. were responsible for the research design and wrote early drafts of the manuscript. C.S.W., Q.F.M., Y.Q.L., and G.G.W substantially contributed to interpreting and revising the manuscript.

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Statement on data availability

The datasets generated during the current study are available from the corresponding authors on reasonable request.

Declaration on conflicts of interest

The authors declare no conflict of interest.

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